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# the literature

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**FOUNDATIONAL TECHNOLOGIES FOR ACTIVITY-BASED INTELLIGENCE—A REVIEW OF THE LITERATURE**

by

James Llinas and James Scrofani

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# ABSTRACT

Activity-based intelligence (ABI) is a discipline of intelligence where the analysis and subsequent collection are focused on the activity and transactions associated with an entity, a population or an area of interest. It is considered a new intelligence tradecraft. This report offers a survey of algorithmic-level literature that has been directly applied to ABI analysis. Areas considered include, ABI- and tactical intelligence-specific approaches, approaches for assessing stages of political unrest and societal radicalization and approaches explored in the field of ambient intelligence. Finally, recommendations of scientific techniques that have potential utility for ABI are offered.

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# TABLE OF CONTENTS

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# LIST OF FIGURES

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# LIST OF TABLES

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# I. THE CHANGING INTELLIGENCE PROBLEM SPACE

Since the fall of the Soviet Union, socio-political dynamics in the World have changed dramatically. While larger nations in the World cannot forget about concerns about and readiness for traditional nation-state conflicts, the nature of what have come to be called “irregular” and “asymmetric” engagements, coupled to significant changes in information technology capabilities have resulted in an intelligence and military problem space that has been labeled as comprising a “mystery” rather than a puzzle [1]. Similar problems in the financial world gave rise to the notion of “Black Swan” events involving surprise and high impact [2], and this notion has carried over to intelligence and military problems as well.

Part of the new complexities of these problems is that they occur in a more or less “normal” context so that distinguishing the meaningful from the irrelevant involves knowing about both settings and behaviors; in many of these cases the “adversary” is not known. Furthermore, if adversaries are known they exhibit adaptive behaviors that make understanding and predicting threatening or anomalous behaviors very difficult. Our term for this problem class is “weak knowledge” problems in the sense that reliable a priori models or procedural knowledge of the expected adversarial or other dynamics are not yet available and thus not available to support deductively-based analyses. As a result, analysis approaches to such problems require mixed paradigms where any available and reliable a priori knowledge can be employed in a deductive framework but at the same time inductive and abductive methods involving learning and discovery operations and tools are also part of any modern analytics suite.

Further challenges arise in these cases because it has been learned that inputs well beyond traditional intelligence, surveillance, and reconnaissance (ISR) sensor data are necessary to aid in inferencing and understanding and for developing situational hypotheses. Intelligence analysis in these environments requires a broad range of heterogeneous data and information to include: open source and socio-political data, contextual information, ontological information (declarative knowledge), and learned information. Much of this data is of a type that is today being called “soft”, generally meaning that it is expressed in language. This has given rise to accelerated development of computational methods to process textual input, but the state of the art remains far from achieving the goal of natural language understanding. As a result, analysis methods are further complicated by the subtleties and vagaries of language and also the complexities of semantics in the large.

We also point out that these problem types impute a relational focus onto the requirements for analysis processes [3]. This is in part because the inherent focus for analyses is on situational and impact estimates, rather than the tactical type focus on singular or grouped physical entities. One general characterization of a "situation" can be said to be "a set of entities in a set of relations," and for the types of problems of interest here, the extent of relation-types is extensive and of high dimension. Said otherwise, states of affairs are composed of entities (in the most general sense of the term – including physical objects, properties, attributes, mental events, temporal sequences, and the like) that stand in relation to one another; it can be argued then that to describe a "state of affairs" or a "situation" is to describe a relational complex. Importantly, these relations for the class of problems addressed here are largely among people—humans—and thus the focus of analysis is also about "human dynamics", and we see for example the Defense Science Board urging for initiatives to enable "Understanding Human Dynamics" [4].

And now, roughly since some papers were released by the Office of the Under Secretary of Defense for Intelligence (OUSDI) in 2010, we see the terminology of "Activity-based Intelligence (ABI)" entering the discussions about intelligence analysis. One source [1] defines ABI as "a discipline of intelligence where the analysis and subsequent collection are focused on the activity and transactions associated with an entity, a population or an area of interest." ABI has also been labeled as a new "intelligence tradecraft", and is also closely coupled to the notion of "human domain analytics" just mentioned. The purpose of ABI has been characterized in [1] as involving the following five elements:

- Collect, characterize and locate activities and transactions;
- Identify and locate actors and entities conducting the activities and transactions;
- Identify and locate networks of actors;

- Understand the relationships between networks;
- Develop patterns of life.

Developing patterns of life (an ill-defined term) also requires an understanding of relationships between various entities and their activities and transactions. In concert with these elements are certain data-centric principles, according to Quinn, in [5], who cites these principles as:

- "geo-reference to discover," which means persistently collecting data on activity and transactions over a broad area or with a variety of sources, then storing it in a database to be discovered later when it intersects with other data.
- "sequence neutrality," which connects to the idea of non-linearity, and that data related to an activity may not exhibit linear temporal, spatial, or other types of sequences—this principle clearly relates to the one above.
- "data neutrality," or the idea that all data is good and not to be biased toward any one data source.

This article also mentions the notion of knowledge management, the need for which we agree with strongly, as this function is critical in any adaptive multi-INT learning or discovery-based inferencing or estimation process. These principles describe ABI as "non-linear" but we see this as simply descriptive of an analysis method that has the characteristics of learning and discovery procedures, being iterative and involving forward and backward inferencing and verification operations. Such processes are also described in the latest characterizations of intelligence analysis as comprising "sensemaking", one description of which involves "articulating and structuring the unknown" [6]. Pirolli and Card, in [7] provide what is the most-cited description of the sensemaking process as a basis of intelligence analysis, involving iterative "information foraging" in a nonmonotonic analysis activity.

Much has been said about ABI in the trade publications of the intelligence community (for example, see [1, 5, 8, 9, 10]) but there has been very little published in the scientific literature that describes particular and novel technical methods that are explicitly supportive of and traceable to an ABI application. Our purpose in this report is to offer a survey of algorithmic-level literature we have gathered and reviewed that has been directly applied to ABI analysis, as well as offering thoughts about and descriptions of scientific techniques having functional relevance to ABI drawn from different application areas that we believe have potential utility for ABI.

## II. ABI REQUIREMENTS AND CHALLENGES

In [11], Tse provides both a good ABI overview and offers a copy of an ABI "Hard Problems" list (developed by the US Geospatial Intelligence Foundation) that we copy below:

1. Advanced ABI data set analysis, including large and small data sets of single, multi-INT, and multi-source types
2. Automation of capabilities to enable anticipatory analysis including alerts, anomaly detection, change detection, object identification, etc.
3. Semantic search, data mining, knowledge discovery/analysis, automated learning processes, and advanced search techniques
4. Responsive, reliable, and efficient cross-discipline/INT/security level content storage, discovery, retrieval and correlation
5. Quantitative handling and propagation of uncertainty/confidence across variable fidelity/ pedigree sources to support decision making
6. Geolocation and registration of activities and transactions with defined uncertainty to support spatial and temporal correlation across multi-INT data
7. Foundation content domain that supports multi-source integration on contextual information including human geography, foundation GEOINT, and structured observables
8. An integrated end-to-end multi-INT ABI framework which enables a flexible and discoverable data processing, exploitation, and dissemination management enterprise
9. Modeling of activities, facilities, entities and patterns-of-life (including complex activities) to enable anticipatory analysis
10. Rapid and relevant multi-INT information correlation across disparate sources (including unformatted/unregulated and non-temporal/non-spatial data)
11. Integration of non-traditional sensor modalities (ie: gravitometry, acoustics, MASINT, other unique sources)
12. Distributed, advanced, and automated data processing (large and small data sets; single-INT and multi-INT)

13. Preparation of system data for more effective cross-sensing domain data integration

14. Automated processing of activities and transactions including extraction, identification, tracking, recognition, and filtering

15. Automated, synergistic tipping and cueing across multiple sensors in operationally relevant timelines

16. Integrated work flow composition to enable responsive analysis capabilities

These "problems" are by and large descriptive of processing and algorithmic type capability requirements but do not offer any requirements in terms of the needs of operational problem analysis—that is, the type of "answers" required—the inferences and estimates or hypotheses desired. Apart from "patterns of life", there is no specificity regarding the output of any given supportive technology. While the list is helpful, it also lacks quantification in terms of scale for the implied independent variables; notice that the word "activity" is not in the list. Interestingly, in relation to the "answers" remark above, the list does not address the need for a taxonomy or ontology of "activities". In [12], a distinction is made between "actions", defined as simple motion patterns typically executed by a single human or entity, and "activities" that involve coordinated actions among a small number of humans or entities (see the section on Hard and Soft Information Fusion below). The purpose of this report is not to enter into a long treatise on the philosophical and ontological aspects regarding the nature and definitions of actions, activity, activities, etc. but it would seem that collecting such material should be one of the foundational elements of formalizing the nature of ABI, toward helping to define what algorithmic methods may be helpful in activity-based analyses. Our web search on this topic rather surprisingly yielded relatively few pertinent citations but we offer a few remarks from them. The edited text [13] has some relevant chapters addressing the ontological aspects of actions and activities; Chapter 1 of [13], by E. J. Lowe argues: "Any comprehensive theory of action should have something to say about the ontology of actions", a point we agree with. This interesting chapter discusses the idea of agents—that perform actions—and also the notions of intentionality in action, and whether events and actions are equivalent, and also the issue of causation of actions, activities, or events.  We stop here on these philosophical subtleties but it should be clear that moving ahead with formalization of ABI as a discipline will require addressing these and other points.  A possible complex activity taxonomy is offered in [14] that nominates six classes as in Figure 1:

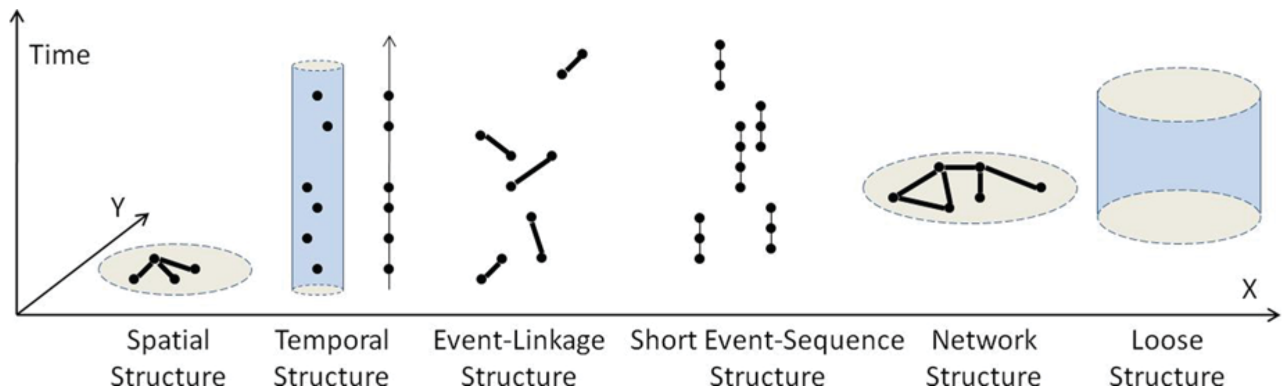


**Figure 1.  Activity Structures Making up Complex Activities (from [14])**

A few other references are in [15, 16] that introduce yet other issues regarding the formal specification of activities such as the temporal aspects of actions and activities.

All of the points in the above list and discussion are helpful toward understanding the features of ABI but our focus is on the specification of methods, techniques and especially algorithmic and analytical capability requirements that the above list does not explicitly define.

## III. A SEARCH FOR TECHNOLOGIES

In addition to studying the IC popular literature, we conducted a literature search on the web, with an explicit focus on ferreting out any scientific works that directly explore ABI-related problems and that nominate and hopefully test and evaluate prototype technological and algorithmic methods. Using our best intuition and experience in nominating adjunct areas of study to ABI, we also explored the literatures of:

- Tactical Intelligence –a subset of works on this topic that focus on activity pattern recognition
- Political Unrest and Societal Radicalization –as we judge that assessing precursor activities leading to radicalization could be one analysis goal of ABI
- Ambient Intelligence –that area of study that explores methods to design smart environments by fusing and exploiting sensor-laden environments toward inferring everyday life activities, tasks and rituals—these are "activity-based" studies on human behaviors conducted from close-range sensing
- Action and Behavior Recognition Literature –these from serendipitous searching on these topics
- Hard and Soft Information Fusion Technologies –these quite-new methods that are studying automated, algorithmic ways to exploit both traditional sensor data and the broad range of data related to ABI comprised of textual, linguistically-framed, semantically-rich, and often unstructured data classes.

We point out that apart from any works directly related to ABI as derived from long-range sensing (our central focus), any promising methods that could be identified from other related application areas and problems immediately impute the issues of scalability and robustness assessment of such methods. Scalability, as a property of systems, is generally difficult to define and in any particular case it is necessary to define the specific requirements for scalability on those problem-space dimensions which are deemed important. These dimensions are the independent variables that "scale" the problem space, and would allow a judgment of similarity of problem spaces to be quantitatively assessed. Scalability can be thought of as involving a search for invariants in the different problem spaces, in the sense of these meaningful dimensions. One example of such variables for the class of multisensor-multitarget tracking (multi-INT) problems are the inter-object spacing, object maneuverability, and the sensor sampling rate (e.g., see [17, 18]), that drive the difficulty of data association and track estimation for fusion-based solutions. This idea is closely linked to the need for an ontology of activities that can aid in defining types of activity-estimation problem classes, and the associated variables that define any class of activities.

## A. SEARCH RESULTS

The search results here are based on a literature base of over 50 journal-type publications, and space does not permit a discussion on all of the findings and judgments from those findings. We focus on communicating the nature of the approaches from a top-level, showing how these researchers think about activity-based problems and analyses, as well as trying to characterize the nature of specific algorithmic solutions, blending top-down and bottom-up views.

## B. ABI- AND TACTICAL INTELLIGENCE-SPECIFIC APPROACHES

Here we found rather few works that were distinctive in taking, what in our judgment was, an ABI-type focus we believe the IC is interested in (we point out that we did not search on or include works dealing with social network analysis (SNA) and related topics which, while related to ABI purposes, focus more on such issues as organizational structure, high-value individuals, and notions of prestige, etc. as typical of SNA analyses). Broadly speaking, these works did employ an activity-based approach to identify adversarial organizational structures and related missions, so in a sense they are not far from SNA-type methods but do address the behavioral aspects more intently than SNA techniques. One of these papers [19] does provide an informative overview of some approaches and specific methods for the problem of modeling and learning of behavioral patterns, and we summarize these viewpoints below.

We consider that one fundamental specific capability required for addressing ABI problems is detection and labeling of coordinated behavior, action, and activity patterns. A non-trivial aspect and characteristic of this problem is that the patterns evolve in time; that is, a pattern develops over and consumes time in its evolution, and is thus only “present” after some time interval has occurred. In addition, the set of activities of interest will typically range over layers or classes, and these structures need to be built up from available data (this again raises the issue of ontological specification of the overall class of activity structures of interest.) One example of a behavioral hierarchy is shown in [19] as in Figure 2:

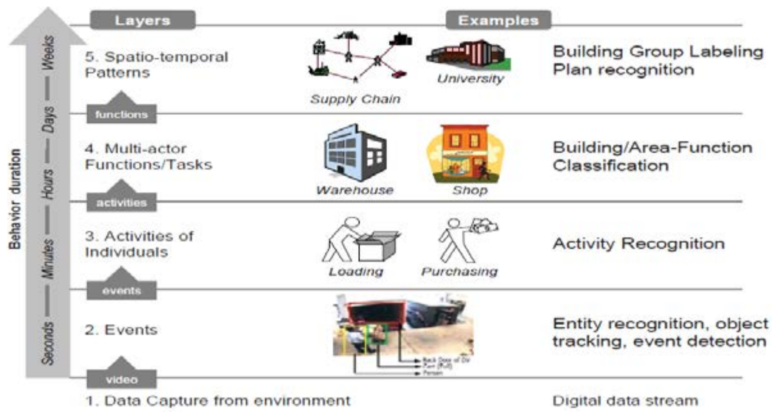


**Figure 2. Example Behavior Class Hierarchy (from [19])**

Although this paper's focus is not specifically on the multisource information fusion, multi-INT issues (although we point out some important fusion issues in our remarks), we note that the development of inferences and estimates of any given type of behavior or activity as for example in Fig. 2 clearly will involve the design and specification of a state of the art information fusion, multi-INT-based process. Some additional remarks on fusion issues are offered in the section below when we address the "hard and soft information fusion" process and its complexities.

As [19] also points out, one is not only interested in observable aspects of activities but also the underlying causal motivations. Classification of activities is also related to issues of resolution and related to this is the issue of "A2AD" or anti-access, area denial aspects of any observational operation. (Recent papers in the defense and IC community have pointedly remarked that virtually all observational data in Iraq and Afghanistan have been taken from nadir viewpoints and at close range; other modern problems such as ABI are not likely to enjoy such favorable conditions.) Additional complexities in behavioral classification defined in [19] are the influence of contextual factors (time-of-day, weather, etc.), latent/unknown factors, and of course the errors, uncertainties, and ambiguities in observational data. Specific methods cited for activity recognition in [19] are: n-grams, stochastic context-free grammars that provide syntactic recognition of the activity process' structure, Hidden Markov Models that enable both recognition of the temporal event structure of the activities from partially observable phenomena and support unsupervised learning-based estimation of activities. ABI analyses will not only be interested in the activities per se but what underlying cause or function is occurring; [19] addresses this issue in various specific techniques for function recognition, such as: Probabilistic Latent Semantic Analysis and the related Latent Dirichlet Analysis technique, and the class of network or graph pattern matching methods. One concept for an architecture that puts all this together is shown in [19] as in Figure 3:

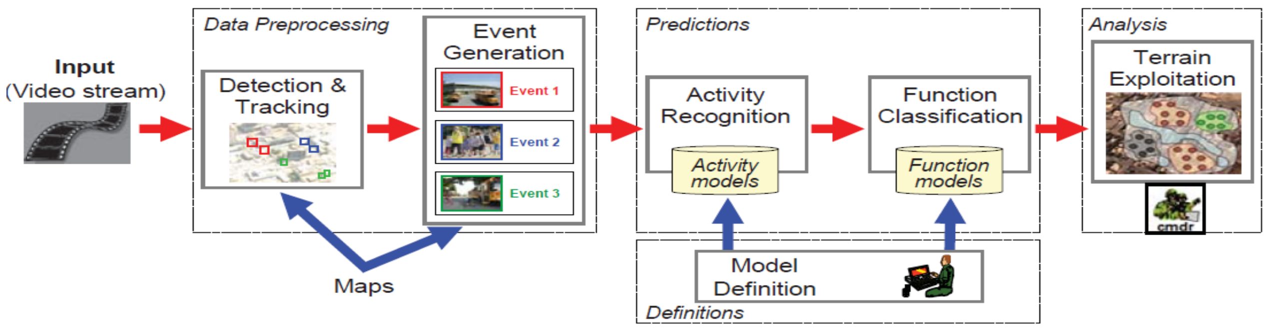


**Figure 3. Notional "Geo-Spatial Behavior Pattern Analysis System" (from [19])**

Levchuk et al [19] conclude their paper with comments regarding research needs toward developing the types of capabilities considered to be required for adversarial behavior recognition. These are shown below, with our own comments added:

- Vocabulary of functions, activities, and events: said otherwise this is the need for behavior, action, activity, function ontologies
- Choice models: these are indirectly intent or causal type models
- Development of models of activities, functions, and mission patterns: at least for model-based approaches, models of course are needed, but learning, discovery and inductively based methods are also needed
- Tracking the state of the behavior signature and iterative prediction refinement: indirectly this is a remark that much current work has been batch/forensically-motivated; this is a statement of need for streaming and also predictive/recursive methods (see the section below regarding hard and soft information fusion)

- Understanding how the behaviors change and can be influenced over time: more or less an aspect of the above in that behavioral state change models are needed; again this could be considered as part of the ontology specification, as many ontologies incorporate temporal aspects
- Dealing with data at different levels of time and information hierarchy: in our view, this is essentially the need for well-designed fusion systems
- Integration of the reasoning and collection planning: this is fundamentally a need for an adaptive, closed-loop process. This involves however the issue of "design authority" meaning whether the reasoning (eg fusion) process designer has authoritative control over collection or not (sometimes problematical in the IC environment); if yes, then an adaptive process can be designed—if not, these processes are disconnected
- Reasoning about the behaviors as well as actors conducting those behaviors, and corresponding data association problems: again we see this as a part of fusion process design, as association is a fundamental function of fusion process design
- Testing and training: these aspects are fundamental to any well-developed technological capability, and especially important are the formation of associable multisource data sets for development, testing and evaluation

In the areas of ABI and what we informally label as tactical intelligence, we survey some dozen papers in Table 1 below that we believe are reflective of our overall survey; these are just a sample. The table columns include the citation, the nature of the input data dealt with, the operational problem addressed, the technical methodology studied, and remarks about any results presented. There is no prioritization or ranking implied in the table.

**Table 1. Sample Survey Results for Papers on ABI or Tactical Intelligence**

| **Paper/Citation (see References)** | **Observational Data** | **Operational Problem** | **Technical Methodology** | **Results** |
|---|---|---|---|---|
| [20] Recognition of Coordinated Adversarial Behaviors from Multi-Source Information | Intell Rpts (No association formalism) re Transactions; some clustering of reports | Adversarial organizational understanding, mission estimation | Model-matching (attributed graphs) using graduated assignment algorithm | Simulation-based results; 70% type accuracy |
| [21] Identifying the Enemy – Part I: Automated | Intell Rpts and Intercepts; association is | Adversarial organizational understanding | Probabilistic attributed Graph | Simulation-based results; high accuracy |

| | | | | |
|---|---|---|---|---|
| Network Identification Model | Individual data-to-model, not data-to-data<br>Do not deal with entity extraction issues, imperfections | , mission estimation | matching algorithm. | |
| [22] Identification of Adversarial Activities: Profiling Latent Uses of Facilities from Structural Data and Real-time Intelligence | Supply-chain reports | Adversarial facility identification | Probabilistic attributed-structural pattern consistency | Good performance if key attributes contained in input reports |
| [23] Activity Recognition in Wide Aerial Video Surveillance Using Entity Relationship Models | Set of distinct tracklets of reasonable duration, presumably derived from wide-area surveillance imagery; real dataset | Broad area kinematically-based activity labeling | Entity-Relation Models for various activities; existing/commercial RDBMS Search tools | Good performance for simple maneuvers/behaviors |
| [24] Relations as Context to Improve Multi-Target Tracking and Activity Recognition | Canadian AI synthetic data; reports of maritime tracks and suspected interplatform relations | Estimates of suspicious rendezvous among various ships | Relational Particle Filter that projects future entity tracks (includes relational transition estimates); Relational Dynamic Bayesian Networks | Limited experiments; fair accuracy |
| [14] Recognizing Activity Structures in Massive | UGS-like GROUND sensor network | Notional pattern-of-life activities on the ground | (1) A methodology is presented for | Concept paper; no empirical results. |

| | | | | |
|---|---|---|---|---|
| Numbers of Simple Events Over Large Areas | | | describing the "structure" of complex activities that span large space-time volumes; this is a kind of ontology. (2)Examples of several techniques are presented for recognizing complex activity patterns given large numbers of simple events from a ground sensor network | |
| [25] Remote Detection of Covert Tactical Adversarial Intent of Individuals in Asymmetric Operations | Hard sensor networks at close range ; UGS-like, inclusive of biometrics | Behaviors, intent of small groups of humans | Nominates fusion-based methods and Transferable-Belief Model and Analysis of Competing Hypotheses techniques. | Technology planning document |
| [26] Uses of Motion Imagery in Activity-Based Intelligence | Primarily motion imagery eg FMV and WAMI | Broadly addresses ABI | Interframe compression, difference coding, motion compensation, techniques from biosurveillance | Concept paper; no empirical results. |

| | | | | |
|---|---|---|---|---|
| [27] Adversarial Knowledge Discovery | Records of various type, mixed with "normal" records | Broad class of problems where adversaries are outliers | Distribution, Density, and Hierarchically-based Clustering; Graph partitioning schemes; ensemble and random forest predictors | Concept paper; no empirical results. |
| [28] CMAP: a Flexible and Efficient Framework for Constraint-based Mining of Activity Patterns | Records of various type that can structured into logical clauses | Use Case involving intell on aircraft operations | Constraint-based Data mining approach to discover patterns as logic clauses (entities connected by relational sequences) | Good results on Use Case; generalization under study—trades off number of constraints vs precision, recall |
| [29] Group Activity Analysis for Persistent Surveillance | Streaming video | Insurgent, terrorist activities; focus on group activities; Game-based simulation expts | Model-based approach using Event graphs, Probabilistic Petri nets; exploits ontological information | Good Precision, Low Recall on Use Case |
| [30] Automated Learning and Visualization of Traffic Patterns from Multi-INT Fused Tracks (DARPA INSIGHT Pgm) | Multi-INT | Insurgent activities; expts at the Natl Training Ctr; forensic approach | Hierarchical, data driven learning approach that builds on fused tracks, cluster development, edge bundling | Overall good performance for NTC Use Cases; provides traffic pattern attributes but does not assign semantic activity labels |

Some of these papers address the broad issues in designing approaches to ABI-type problems, such as [14, 25, 26, 27]. Of the papers that experiment with specific techniques, the techniques span a variety of probabilistic pattern-matching approaches, with many using graph-based strategies. Notions of inter-source data association are surprisingly missing in many of the references. It is clear that robust toolsets for ABI will require layered and hierarchical approaches that span localized, single-entity behaviors to abilities to semantically label group or otherwise aggregated activities. Our list of named methodologies derived from these and related readings are:

- Probabilistic plan recognition
- Probabilistic attributed graph matching
- Probabilistic attributed-structural pattern consistency
- Relational Dynamic Bayesian Networks
- Assignment algorithms
- Hidden Markov methodological variants
- Entity-Relation Models
- Relational Particle Filter
- Constraint-based pattern mining

As might be expected, many of the methods studied are based on the class of graph-analytic methods, since activities are patterns and a very efficient way to model and represent patterns is through the use of graphical representations. There are some interesting state of the art, survey type papers on graphical methods in [31, 32]. Figure 4, from [31], shows a taxonomy of graphical representations classified according to their temporal dependence and structural nature.

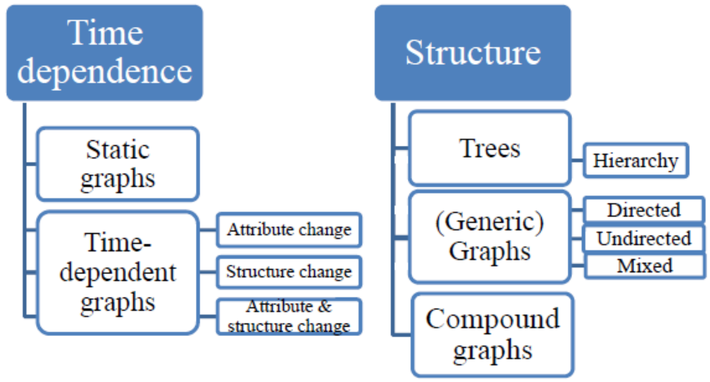


**Figure 4. One Classification of Graph-Analytic Representations and Methods (from [31])**

We emphasize however that providing effective technological and automated support to ABI-type analyses will not be fully aided or solved by singular methods but by a layered, multi-tool architecture; it is because of this that we have included some of the "concept" papers in our review, since developing strategies for toolset architecture will be as important as designing and selecting the component, individual tools (as depicted in Figs 2 and 3).

## C. APPROACHES FOR ASSESSING STAGES OF POLITICAL UNREST AND SOCIETAL RADICALIZATION

The importance of understanding population dynamics has been well demonstrated in the Iraq and Afghanistan experiences over the last decade. As the United States approaches the post-Afghanistan era, and likely enters into an era where the primary missions will involve stability, security, transition, and reconstruction efforts, continued development of capabilities to aid in understanding important societal trends will remain a technological priority. This need was recognized as early as in 2009, when the Defense Science Board issued its report on "Understanding Human Dynamics", as previously pointed out [4], that reviewed and evaluated the state of the art at that time. In searching for ABI-related literature, we encountered a set of materials on political dynamics that we felt to be relevant to ABI analytical methods, and summarize those findings in this section.

In these papers, there is a direct focus on what could be called “patterns of life”-based analyses, derived from an integrated framework of pattern-discovery type tools; all of them take what can broadly be called a computational social science approach. In [33] for example, a suite of Social Network Analysis, Sentiment Analysis, and Investigative Data Mining tools, linked to various text-processing components (since some of the data in this case are Open Source and largely textual) such as Named Entity Recognizers and Relation Extractors are tied in to various “INT” feeds (although this paper again does not address the Data Association problems). In a similar way, [34] develops a framework for analysis of trends in diaspora type environments that employs pattern-matching methods in concert with a theory called Social Movement Theory [35] that examines resource mobilization, opportunities and constraints, and stochastic situational frame structures to develop a sense of what is called the diffusion of social movement across different social strata, as an indicator of how significant social movements propagate. It can be seen from the table entry that yet other tools are used in a multitool approach. In [36], a kind of set-covering approach is used to address the challenge of finding the smallest (or at least a small) set of patterns which “cover” all observed occurrences of an event of interest, using pattern analysis and backward chaining. As can be said as true of sensibly all ABI-related methods surveyed here, [37] argues that there is no single major indicator of activities or phenomenology of interest in these problems; all analyses will require a set of heterogeneous tools, and an imputed challenge will be in developing automated support toward integrating tool outputs into a coherent whole hypothesis of interest.

**Table 2. Sample Survey Results for Papers on Political Unrest and Societal Radicalization**

| **Paper/Citation (see References)** | **Observational Data** | **Operational Problem** | **Technical Methodology** | **Results** |
|---|---|---|---|---|
| (33) Detecting Social Polarization and Radicalization | Open-source data plus Intell, Multi-INT | Detect trends and assess risks of social polarization and violent radicalization | Named Entity Recognizer Relation Extraction System Sentiment Analysis System | None; proposed prototype |

| | | | | |
|---|---|---|---|---|
| | | | SNA Investigative Data Mining | |
| (34) Transnational Islamic Activism and Radicalization: Patterns, Trends, and Prognosticators | None; framework paper | Theoretical and conceptual framework for understanding, recognizing, and anticipating Islamic social reform movements | Social Movement Theory Linear Temporal Logic Influence Diagrams Various other theories and models | Provides a causal structure for the interrelationships among the myriad features of a social movement. |
| (36) Computational Methods to Discover Sets of Patterns of Behaviors that Precede Political Events of Interest | High level political factors drawn from separate socio-political analyses | An approach to identify sets of patterns of behaviors which precede political events of interest such as the onset of regime change, insurgency, ethnic violence, etc. | Greedy set covering pattern analysis and backward chaining | No empirical results |
| (37) The Violent Islamic Radicalization Process: A Framework for Understanding | None; framework paper | Building of a framework to understand social polarization and violent radicalization | Inductive reasoning | The findings herein confirm wide agreement that no single prescribed path of radicalization exists. This study has also identified the criticality of the mobilization component of the radicalization process. It has identified behaviors and combinations of behaviors to be |

| | | | | |
|---|---|---|---|---|
| | | | | studied further as indicators of radicalization and mobilization leading to acts of terrorism. |

Our list of named methodologies derived from these and related readings are:

- Named Entity Recognition
- Relation Extraction System
- Sentiment Analysis System
- Social Network Analysis
- Investigative Data Mining
- Inductive reasoning
- Social Movement Theory
- Linear Temporal Logic
- Influence Diagrams
- Greedy set covering pattern analysis and backward chaining

where, as noted above, it is again emphasized that no single approach or analytical tool will be sufficient for a complete analysis. This list adds some methods needed for dealing with textual and linguistic type data, addressing more pointedly the issues that such soft data introduce—more is said on these issues the section below where we remark on the soft-hard data fusion issue.

## D. APPROACHES EXPLORED IN THE FIELD OF AMBIENT INTELLIGENCE

Ambient Intelligence (AI) is a field of study generally having to do with smart environments that adapt to human activities within them. The activities of interest are usually labeled as "activities of daily life" (the abbreviation "ADL" is littered throughout this literature), and an aspect of the smart environments is that they are instrumented with "multi-INT" sensors, whose data are used for inferencing and estimating the type of activities being performed. While this type of application, involving close-range sensing and no overt adversarial actions such as deception etc., is not that close to intelligence-based ABI applications, we include it because this field is quite active and considerable levels of technology that may be extensible to ABI are being developed. Although the problem spaces are not adversarial, they are non-cooperative and do not depend on any helpful actions on the part of the humans involved.

Two of the papers we include in our survey (see the first two entries in Table 3) are themselves surveys and so collectively provide a comprehensive look at the field, although they are a few years old. In [38], a figure is provided that neatly summarizes their view of the AI field; that figure is shown here as Figure 5:

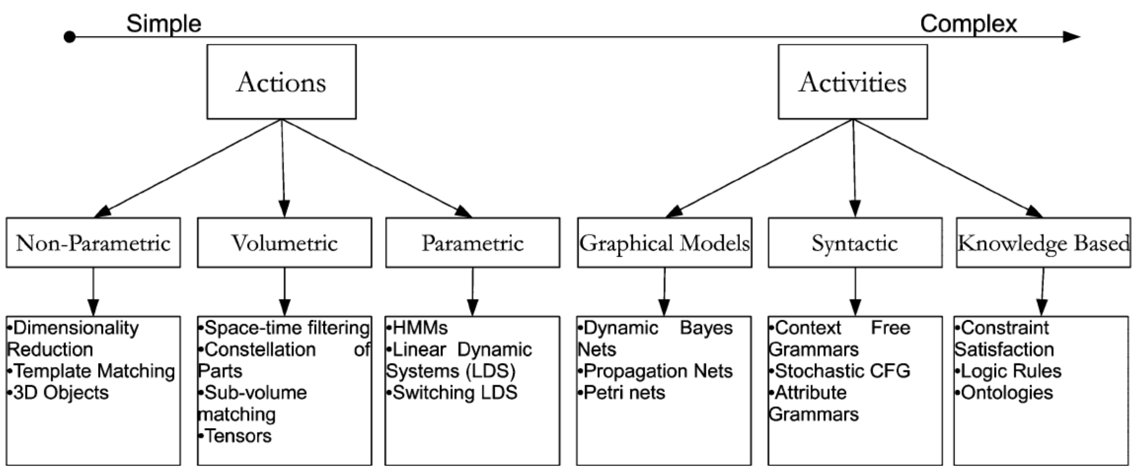


**Figure 5. Overview of the Approaches Employed in AI (from [38])**

Notice that [38], as we remarked earlier, partitions the domain into "Actions" and "Activities", where actions are characterized by simple motion patterns typically executed by a single human in these environments, and activities are considered as more complex and involve coordinated actions among a small number of humans in these definitions. Notice too that some of the methods listed in Fig 5 are the same as or similar to methods enumerated for the prior application areas, hinting at possible employment for ABI-type applications, if scalability issues can be addressed. The second paper in Table 3 [39], addresses the ontology issue more directly, and describes activities in the fashion of Figure 6, leading to the formulation of a formal ontology briefly described in the paper:


**Figure 6. Conceptual Model of an Activity (from [39])**

As noted in our introductory remarks, we are supportive of the need for an equivalent specification of ontologies for any given ABI-class of problem. Our sampling of AI papers is shown in Table 3:

**Table 3. Sample Survey Results for Papers on Ambient Intelligence**

| Paper/Citation (see References) | Observational Data | Operational Problem | Technical Methodology | Results |
|---|---|---|---|---|
| (38 4) Machine Recognition of Human Activities: A Survey | Input video or sequence of images; | Activities of Daily Living (ADL); Behavioral Biometrics | This survey focuses exclusively on approaches for recognition of action and activities from video | Review a range of approaches, summarizing benefits and disadvantages; summarized in figure below |
| (39 1) Ontology-based Activity | No explicit data; this is a survey paper | Activities of Daily Living (ADL) | Description logic based semantic | There is a need for an explicit commonly agreed representation |

| | | | | |
|---|---|---|---|---|
| Recognition in Intelligent Pervasive Environments | | | reasoning coupled to ADL ontologies | of activity definitions, i.e., ontologies, for activities that are independent of algorithmic choices, thus facilitating portability, interoperability and reuse and sharing of both underlying technologies and systems. |
| (40 2) Activity recognition on streaming sensor data | Use Cases employed dense multispectral sensors | Activities of Daily Living (ADL) | Support Vector Machine to classify activities | Classifications of activities ranged from 60% to 75% accuracy. Raises the important issue of interleaved events and activities. An important challenge with this approach is identifying the optimal window size. |
| (41 3) Exploring semantics in activity recognition using context lattices | Two real-world test data sets from high-tech smart homes with dense sensors | Activities of Daily Living (ADL) | Context Lattice | Outperformed Bayes and Decision Trees for activity recognition |

# IV. PREVAILING ISSUES

## A. THE ISSUE OF FUSING HARD AND SOFT INFORMATION

The experiences of Iraq and Afghanistan have also shown that inputs and supporting information (such as contextual information, either real-time or in static databases) of a textual, linguistic type have proven helpful if not critical toward yielding improved intelligence analysis capabilities. This type of information has come to be called “soft”, to distinguish it from “hard, physics-based” data provided by the usual repertoire of ISR sensing devices across the electromagnetic spectrum. In most of the papers reviewed here, such data are considered to be part of the input or observational data, along with sensor data; the multi-INT problem of interest can then be characterized as a hard + soft information fusion problem. However, very few of the papers included here address the daunting challenges of the hard + soft fusion problem with any rigor. Linguistic data immediately impute the long-studied problem of natural language understanding, with all of its complexities, as well as introducing the complexities of semantics. It is only in the last 5 years that the information fusion community has addressed this class of problem, and the evolving technological capabilities are only recently beginning to evolve out of the academic community. The Center for Multisource Information Fusion (CMIF) at the University at Buffalo, Harvard University, and the University of Washington are leading multi-university teams in 5-year programs under Army Research Office funding to study and develop prototype capabilities to rigorously deal with the challenges of the hard + soft fusion problem (see [42, 43, 44] for some overview papers). Robust architectures that provide meaningful automated support for ABI analyses and the evolving ABI tradecraft will need to include not only the tools described herein as derived from directly and indirectly-related applications, but also integrate the formalisms of methods to address the hard + soft multi-INT fusion problem.

## B. EXTENSIBILITY AND SCALABILITY

Finally, we offer a brief reminder that while any given (and properly-defined) ABI problem may possibly be addressed by the various methods described herein, there are issues to consider. Even methods that have been applied to what is considered a directly-relevant ABI problem need to be carefully reexamined for extension and scalability to a particular ABI problem; while there may be low-hanging fruit across the capability-spaces reviewed here, careful assessments of extensibility and scalability need to be made for future specific applications.

# V. CONCLUSIONS

This report tries to provide an exploration of the range of current technological methods being used for ABI and ABI-related problems, toward providing an initial view of that inventory as a resource for needed initiatives in well-planned development and realization of the scientific foundations that will allow ABI to mature into a new and needed intelligence discipline. Raetz [45], offers the following perspective on ABI: "ABI holds the same promise for imaging the Human Domain that the invention of the camera held for imaging physical terrain; however, new methodologies, workflows and perspectives are needed to ensure that the benefits of Human Domain analysis are fully explored." Raetz champions a layered-graph system type approach toward uncovering layered systems of what we have called here "relational complexes" among sets of activities and transactions. That approach at least recognizes that a layered, multi-tool type analytical framework is required to address the analysis challenges of ABI. But the integrated challenges of ABI will require defining and prototyping new analysis process designs that effectively deal with big-data levels of multi-INT that likely include more soft data than hard, equally large amounts of contextual data, suites of helpful but disparate automated tools, in a discovery/learning/sensemaking process that importantly includes dependencies on human intelligence, and finally is dynamic and adaptive. Raetz is correct we think in pointing out that to achieve efficient and effective frameworks for ABI analysis will require new methodologies and workflows but we would add that the meta-issues that will throttle the ability to achieve such capability are the identification and enablement of a structured basic research program to assess and identify potentially new, innovative, currently unknown foundational technologies to aid in analysis, and a parallel initiative to more fully understand how to design analysis environments that robustly support dynamic human-machine-based inferencing, estimation, and reasoning. The Center for Multi-INT Studies (CMIS) at the Naval Postgraduate School has conducted various multi-INT studies pertinent to ABI, and is supporting the sponsor community in providing national Multi-INT research leadership, expanding the number, breadth, and depth of researchers conducting high-value Multi-INT research; these efforts are delivering high-value research outcomes, e.g., [46-47]. CMIF and CMIS seek to encourage similar emphasis and coordination in this area. We consider that the role of academia in this overarching initiative is quite large. Tse, in [11], addresses this directly, suggesting “where academic partners can help” in a list including: Automated policy-based ABI enterprise collaboration methods and tools, Multi-modality information representation, organization, access and mining, Information integration and multi-modality intelligence association (as we have pointed out above, an often-overlooked requirement), and in Enterprise Mission Management, related to our point on the design of holistic environments. As regards the Intelligence Community, such academic initiatives can be supported in part by such programs as the IC Postdoctoral Research Fellowship Program, if a coordinated focus on the ABI requirements can be developed. In sum, there is a need for a partnered, government-industry-academic balanced and integrated approach to identify and develop the scientific and technical foundations that will support robust ABI analytical capabilities going forward.

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